MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

The Michigan-Ontario Ozone Source Experiment (MOOSE) Landfill Drone Project

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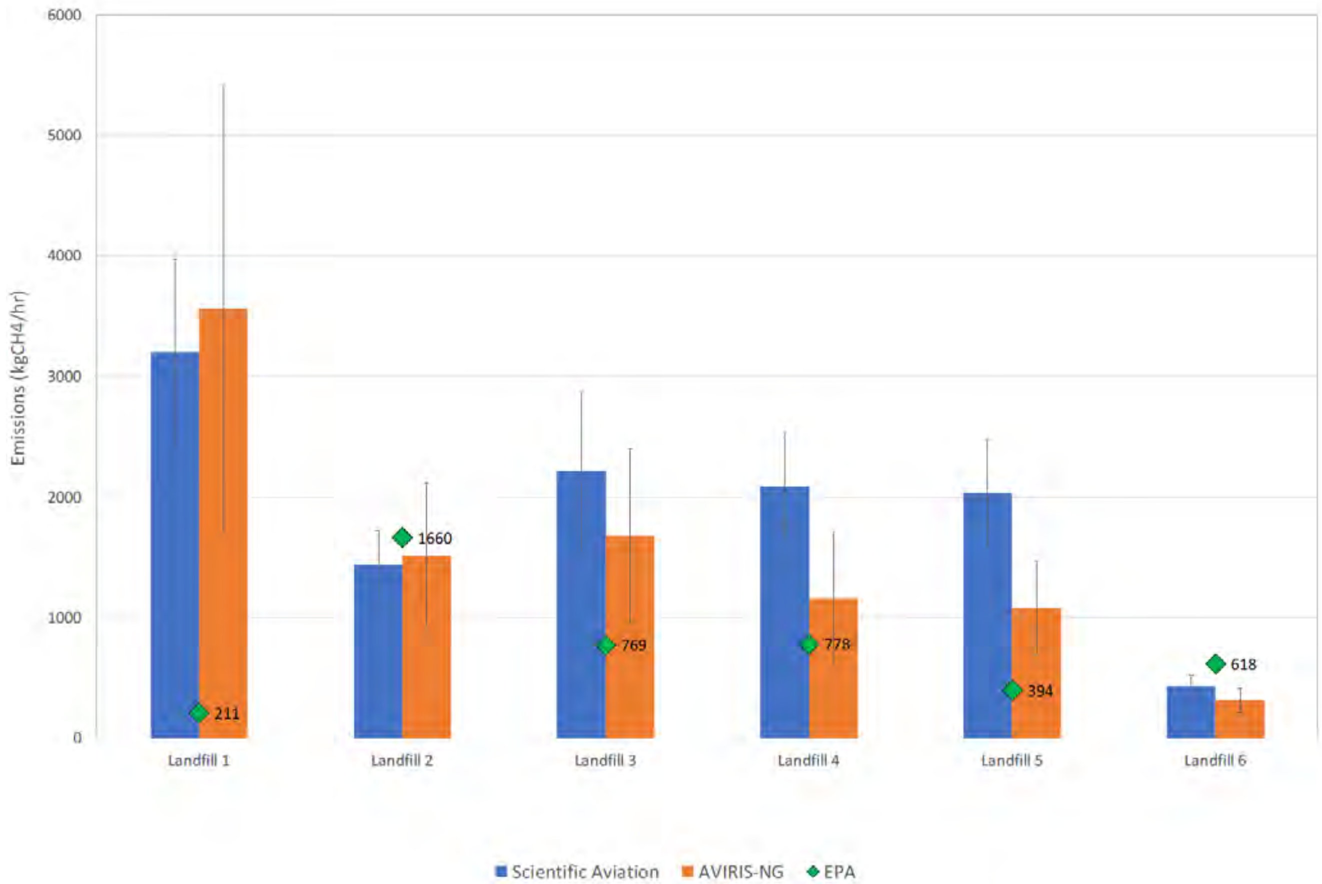
Rationale for the Project

- Part of the MOOSE sub-experiment called Methane Releases from Landfills and Gas Lines (MERLIN).
- Methane (CH_4) is the second most powerful greenhouse gas after carbon dioxide (CO_2).
- Methane is also a global ozone precursor, although it is not classified by EPA as a VOC.
- Large emissions may compensate for methane's low reactivity and enhance local ozone.

California Methane Survey: Landfills



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U.S. EPA R5 GMAP

EPA Region 5’s Geospatial Monitoring of Air Pollution (GMAP) platform uses advanced technology fast response instruments and a precise global positioning system that maps air pollution patterns around sources.

This system uses a mobile platform to measure

- hydrogen sulfide (H_2S)
- methane (CH_4)
- benzene (C_6H_6)
- ozone (O_3)
- meteorological parameters (wind speed, wind direction)

By integrating these parameters with a concurrently collected geospatial tag from an incorporated global positioning system, the platform can be used to obtain highly sensitive ambient measurements to quantify air pollution concentrations, identify sources, and evaluate geospatial impact.

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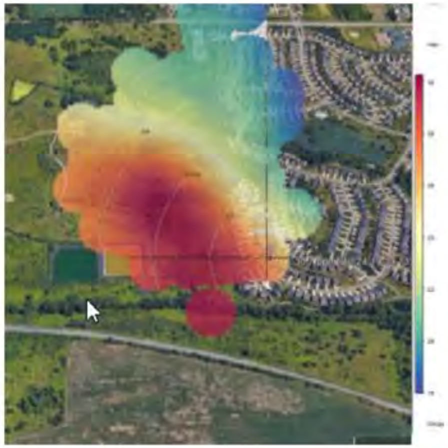

Source: USEPA

MPAL – Michigan Pollution Assessment Laboratory

Mobile air quality lab designed as part of a 10 year study of air quality levels in SW Detroit and impacts of the new Gordie Howe International Bridge.

- Area has potentially vulnerable populations, e.g., elderly and children.
- Inform health impact assessments and epidemiological studies
- Complement data collected from stationary regulatory sites.

MPAL consists of a 2018 Ford Transit truck equipped with fast-response air quality and meteorological sensors.

- Gases: CO_2, CO, CH_4, H_2S, H_2O, O_3, NO, NO_2, SO_2
- PM: PM_{10}, $PM_{2.5}$, PM (7 nm - 20 μm)
  PM composition: black/brown carbon, trace metals (e.g., Pb, Zn)
- Meteorological and other sensors, GPS, video, battery power (7+ kWh).

Source: Dr. Stuart Batterman

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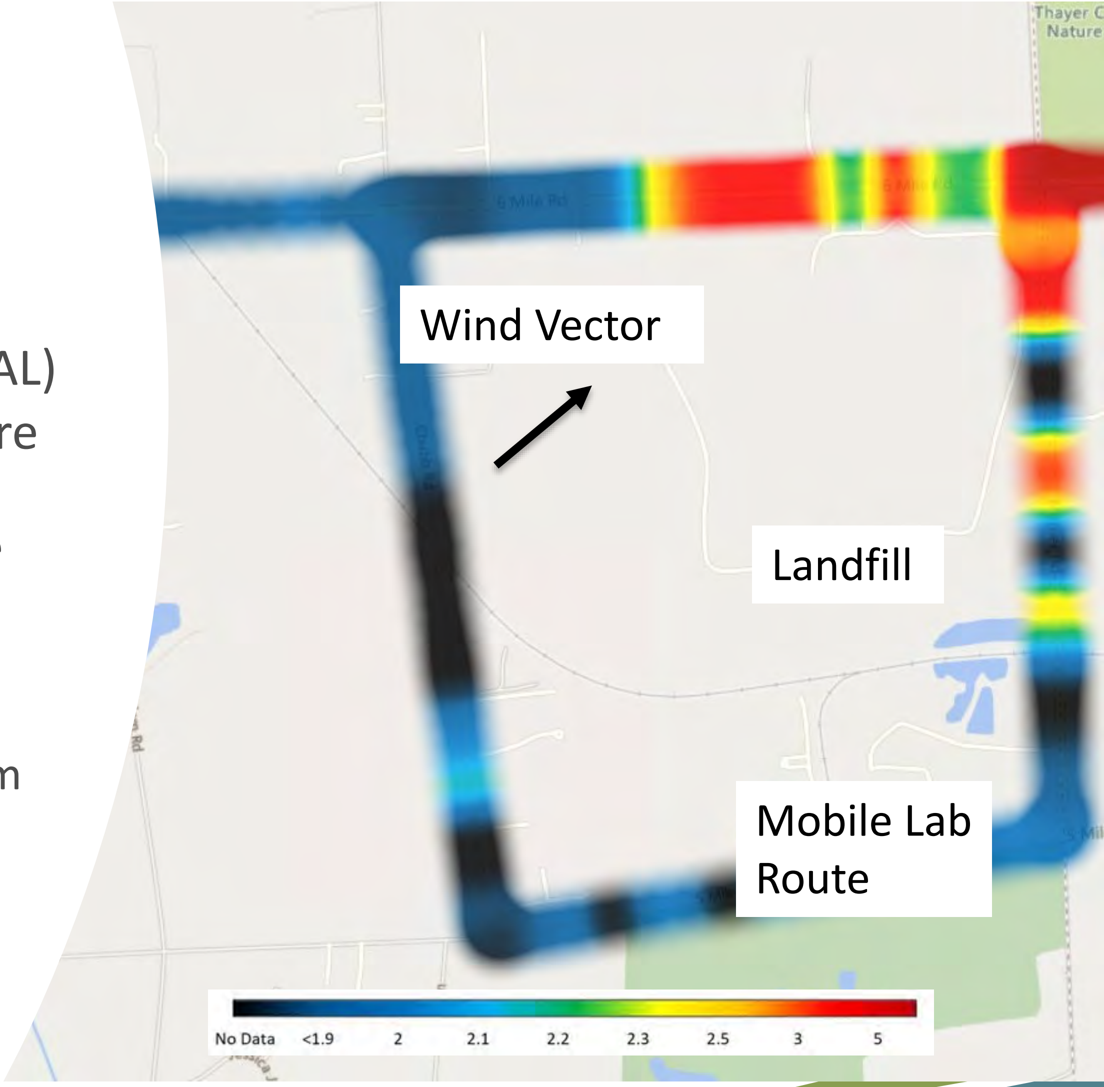
Gaussian Plume Inverse Model

- Recoded main aspects of AERMOD forward dispersion model, including complex terrain features, in the Python language.
- Added an inverse modeling feature based on a multilinear equation solver for non-square coefficient matrices (optimization problem).
- Boundary layer structure computed for both stable and convective cases based on available airport or site-specific meteorological data.
- Ambient air measurements and potential source locations are assigned to horizontal grid cells with 10 m or 100 m resolution.
- Total emissions may be specified as a model constraint and inferred from the performance statistics of various scenarios. Without this constraint, the model may grossly overestimate total emissions.

Data courtesy of Stuart Batterman

Case 1: June 5, 2021, 7:10 am – 7:27 am

- Wind speed = 1.8 m/s, wind direction = 246˚ (based on MPAL)
- Pressure = 979 mb, temperature = 294.5 K (based on MPAL)
- Stable boundary layer with the following parameters:
  - Roughness length = 0.1 m
  - Cloud cover = 50%
  - Inferred mixing height = 136 m
- Cell resolution: 100 m



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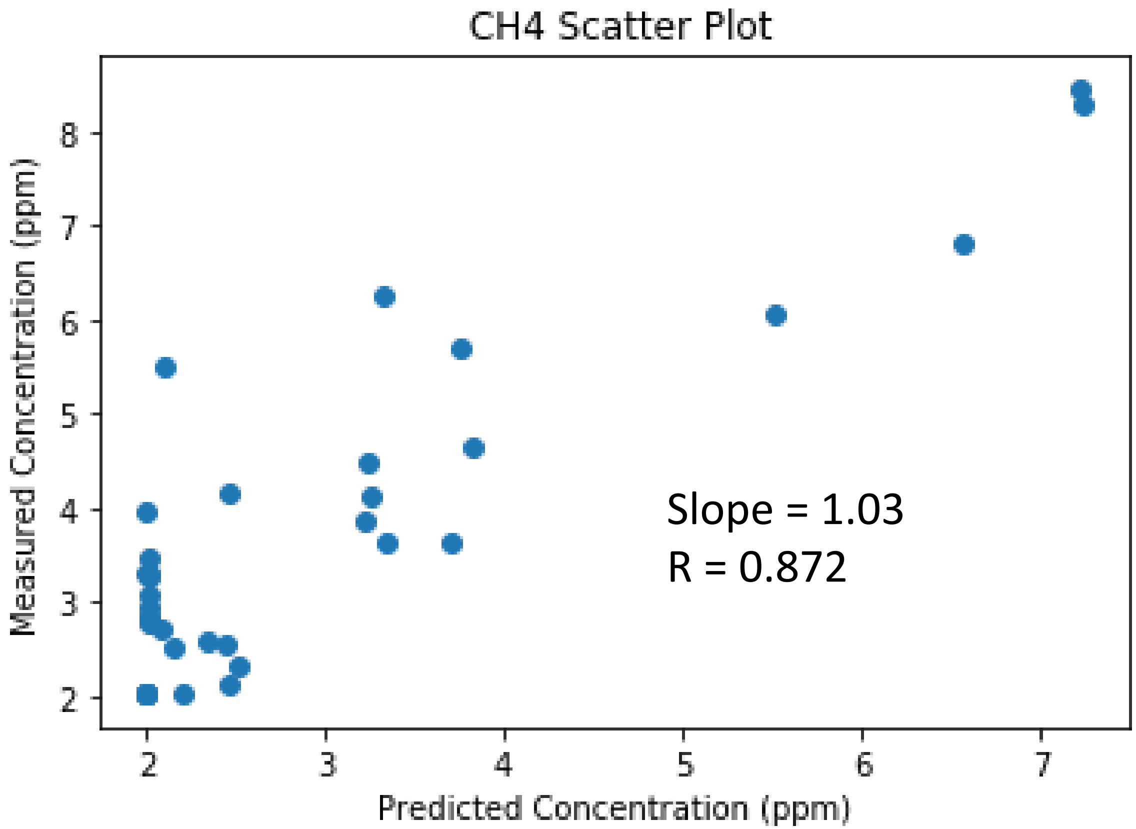
Case 1: June 5, 2021, 7:10 am – 7:27 am Inverse Model Performance



Total Methane Emissions = 500 kg/h

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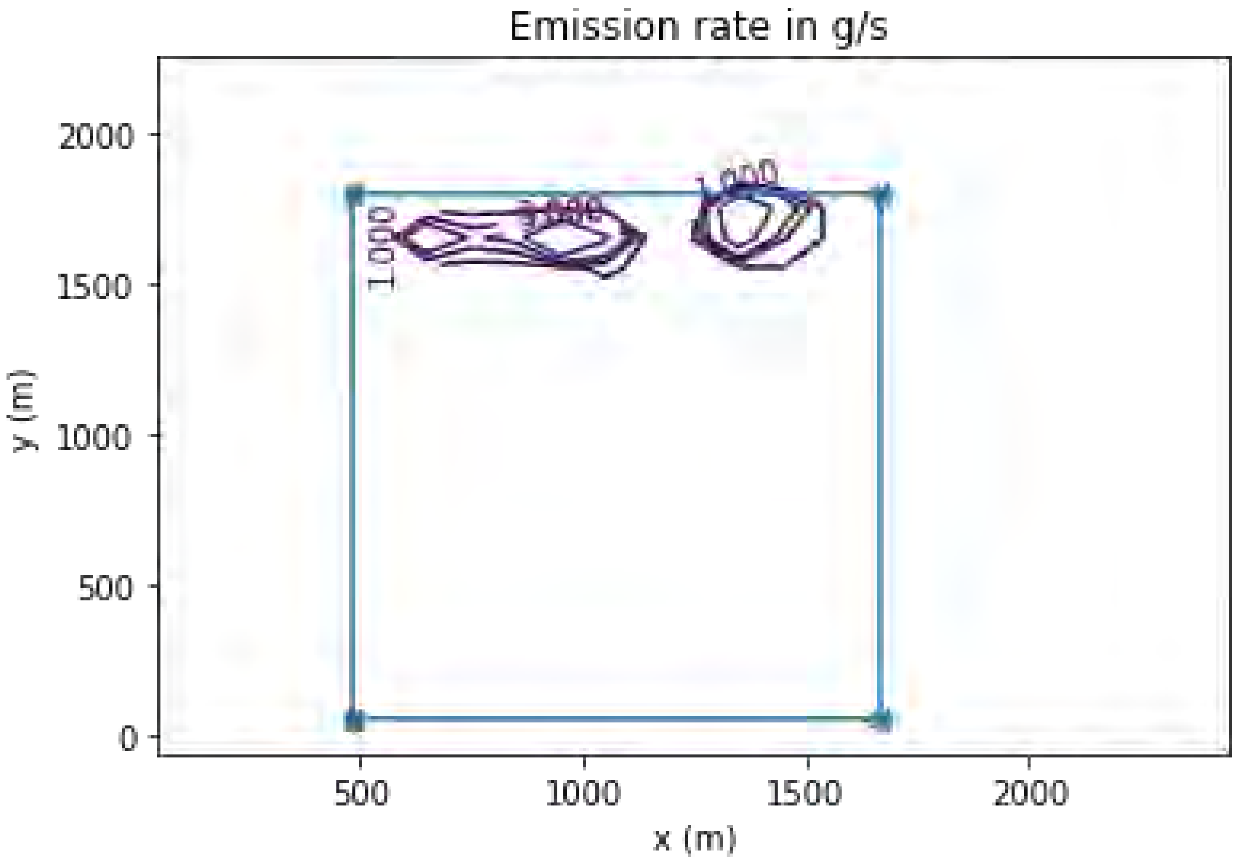
Case 1: June 5, 2021, 7:10 am – 7:27 am Inferred Emissions Distribution



Total Methane Emissions = 500 kg/h

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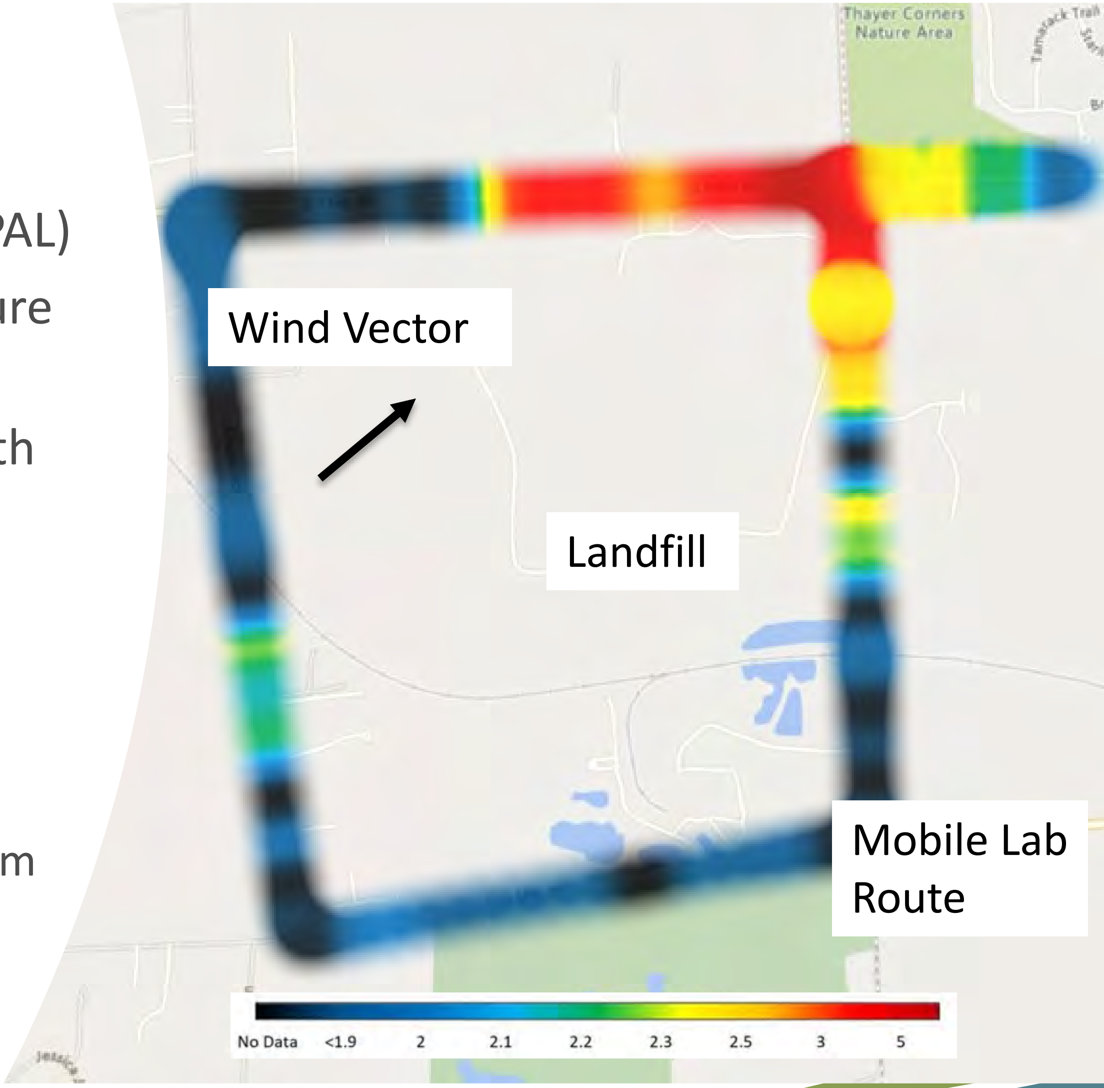
Case 2: June 5, 2021, 10:24 am – 10:39 am

Data courtesy of Stuart Batterman

- Wind speed = 3.1 m/s, wind direction = 246˚ (based on MPAL)
- Pressure = 980 mb, temperature = 299 K (based on MPAL)
- Convective boundary layer with the following parameters:
  - o Roughness length = 0.1 m
  - o Cloud cover = 50%
  - o Albedo = 0.23
  - o Bowen ratio = 0.55
  - o Inferred mixing height = 431 m
- Cell resolution: 100 m



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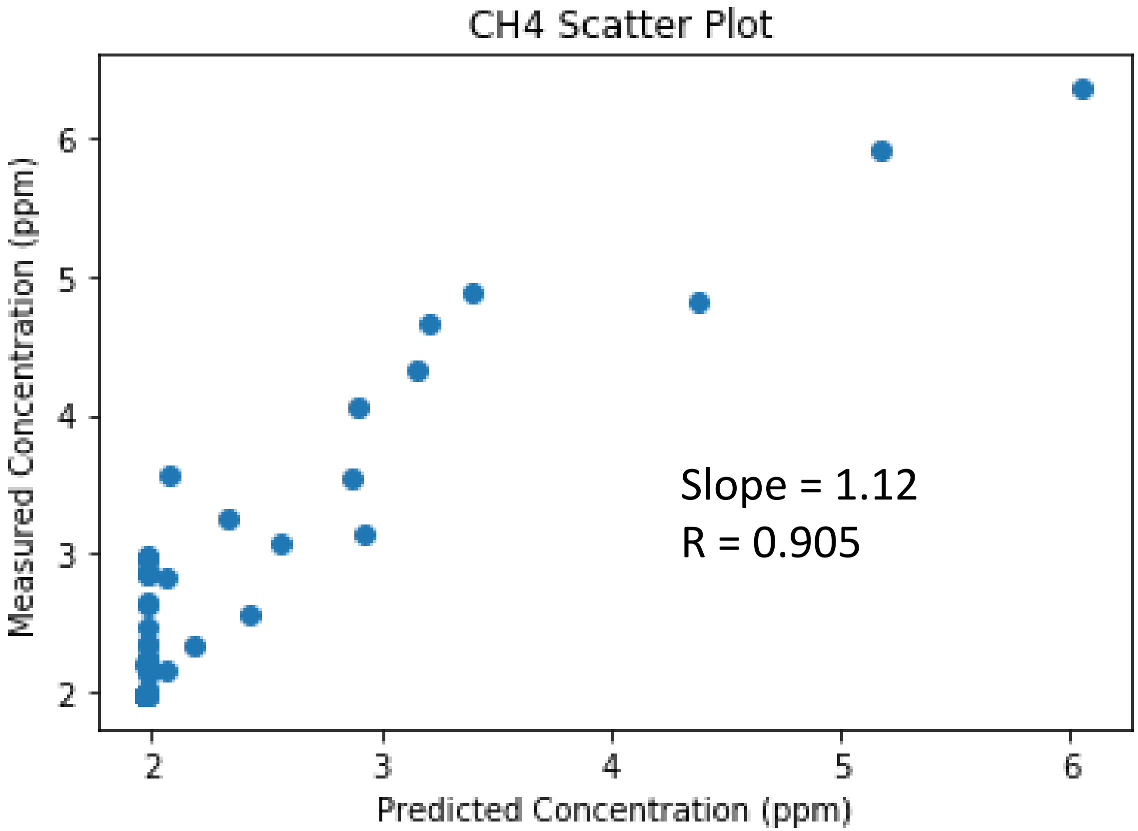
Case 2: June 5, 2021, 10:24 am – 10:39 am Inverse Model Performance



Total Methane Emissions = 3000 kg/h

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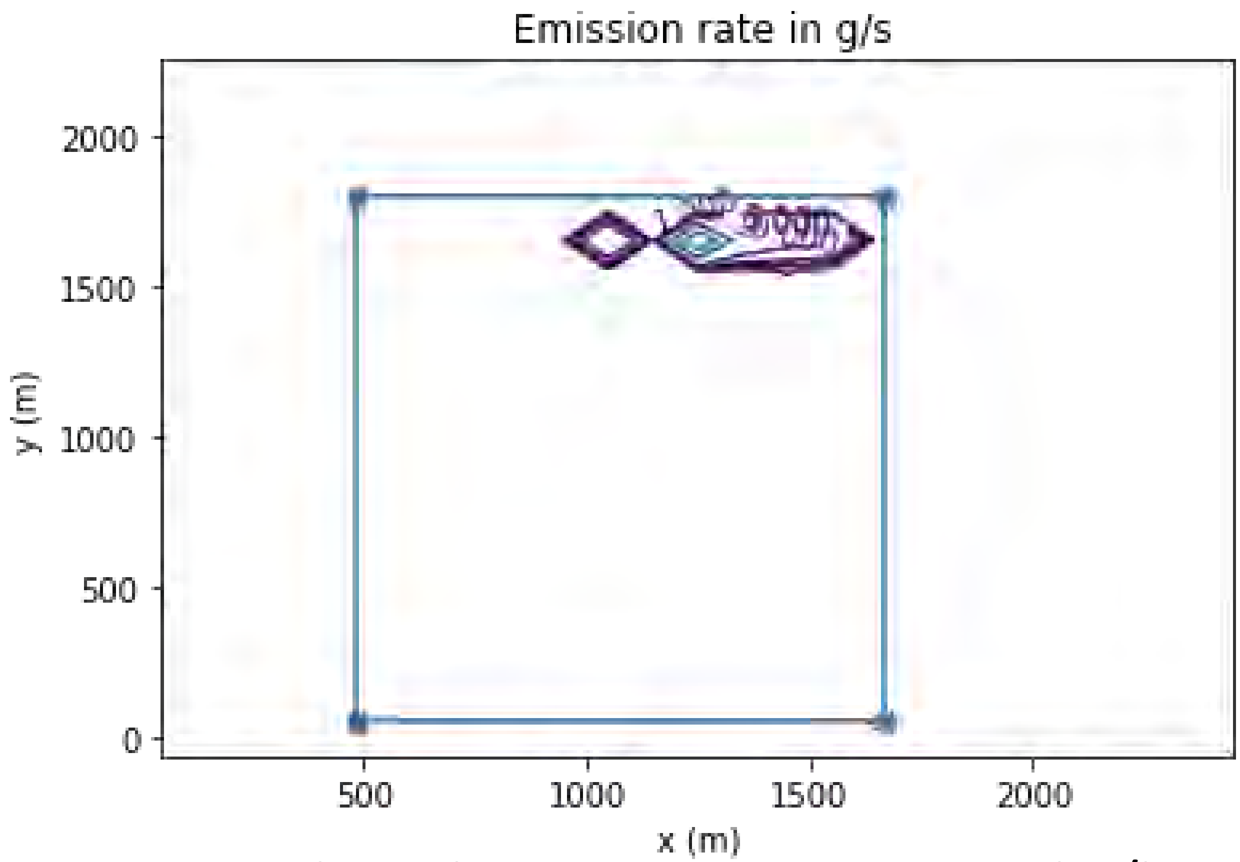
Case 2: June 5, 2021, 10:24 am – 10:39 am Inferred Emissions Distribution



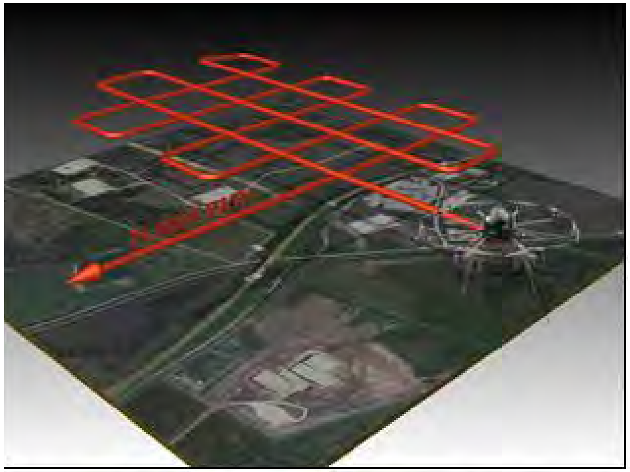
Total Methane Emissions = 3000 kg/h

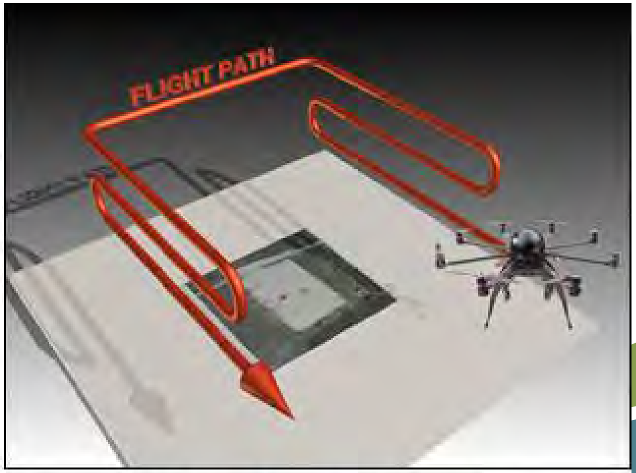
Limits of Using Mobile Lab Data

- Significant pollutant **plumes may be transported above the surface** whose concentrations are not well represented by surface measurements.
- **Need both near-surface and elevated concentration measurements** to improve accuracy of inverse model results.
- Inverse model is **sensitive to the assumed total emissions.**
- Inverse model can also be **better constrained if total emissions can be directly measured** by summing pollutant horizontal fluxes through vertical planes. **Need vertical wind profiles** for this.

Drone Measurements at Landfills

- Two drone measurement platforms:
  - ❑ Aegis IEV2 drone with BlueHalo WP-V2 UAS Weather Payload
  - ❑ DJI M600 heavy-lift drone with a Scentroid DR1000 and a CH_4 Tunable Diode Laser Absorption Spectrometer (TDLAS)
- Negotiated access to 2 landfills in SE Michigan





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2.1 Gas detection specifications for LGD Compact-A CH4

Reference conditions (if not otherwise specified): operating temperature 20°C, pressure 1013 hPa and humidity 45% r.H., power supply 10 - 30 VDC

Parameter	Unit	Value / Range	
Principle of measurement	-	Tunable Diode Laser Spectroscopy (TDLS)	
Target gas	-	CH_4	
Measuring range	ppm	0 – 100 (Full Scale)	0 – 40'000 (Full Scale)
Lowest Detection Limit[1] 2σ	ppm	$\leq$ 0.4 $\leq$ 0.15 with 10 s averaging[2]	
Precision[3] 2σ	ppm	$\leq$ 0.8 $\leq$ 0.25 with 10 s averaging	$\leq$ 250 $\leq$ 100 with 10 s averaging
Sampling rate	Hz	2	
T_{90} time	s	$\leq$ 1.8 at 2 l/min	
Resolution	ppm	0.01	
Accuracy[4]	% of FS	± 2	
Linearity and repeatability	-	included in the accuracy	
Cross interference	-	Gas matrix and application dependent	
Temperature limitation	°C	-10 to +50	

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Summary of Method

- Mobile lab will identify significant plumes at surface.
- A small number of flux planes will be determined based on measured concentrations above background.
- Total net outgoing flux (over background) will be used to constrain total emissions in inverse model.
- Mobile lab and/or drone measurements both inside and outside landfill will drive inverse model.
- Handheld SEM5000 and IR camera will be used to perform ground truthing of inferred emission hotspots.

Problems during Field Trials

- Intense truck traffic near fence line creates significant turbulence and distorts the measured wind fields (negative fluxes).
- Calm winds near sunrise create uncertainties in magnitude and direction of fluxes.
- Rise of boundary layer height due to onset of convective instability dilutes the signal.
- Some wind directions limit drone flight patterns due to obstacles (e.g., power lines).

Preliminary Indications

- Drone method is capable of measuring methane fluxes greater than 500 kg/hr.

- Landfill emission hotspots (including active face) inferred from Gaussian plume inverse model agree qualitatively with SEM5000 measurements.

- Emissions may vary significantly during day, along with truck traffic, landfill activities, and weather.


Questions?